T17

(34)

KVARN
TORP

Svenska Skifferolje Aktiebolaget

Introduction

When the epoch of liquid fuels began with the opening of the first oil wells about 1860, the conditions were created for the enormous technical development which motorization brought about within industry, commerce, agriculture and transportation. Although the world's oil reserves have so far been adequate, the continuing rapid advance in the use of motor vehicles has created an oil demand which the petroleum industry has not always been able to satisfy. This is largely due to the uneven distribution of these reserves over the face of the earth. The struggle of the nations for their vital needs has often been centered around oil. Great resources have been mobilized in order to develop new liquid fuels comparable or superior to petroleum, and the recovery of oil from oil shale figures prominently among the possibilities of utilizing other available sources of supply. Oil shale deposits of varying sizes occur in most countries, bearing potential oil reserves estimated to total more than 110 billion tons.

Research into oil shale was commenced in Sweden as early as the 19th century, activities being intensified during the first World War. During the initial phase of World War II the Swedish Government, in the emergency which arose, started large-scale recovery of oil from shale in an effort to satisfy the most essential fuel needs of the nation. By mobilizing a large number of technicians and the necessary equipment, a plant was built which furnished the nation with a valuable and indispensable supplement of liquid fuels. When imports of petroleum could be resumed when the war ended, this plant was expanded and improved in order to make production profitable.

The Swedish oil shale is of low grade, its oil content ranging from 4 to 7 percent. Therefore, a thorough study of production methods designed to attain the highest possible efficiency in oil recovery and the utilization on a commercial basis of the valuable by-products of shale were primary conditions for economic operation of this industry. These conditions have been the guiding principle in the work of rebuilding the

shale oil plant. Most of this work is now completed and, at the present time, several by-products are obtained in addition to oil. These include sulphur, as well as lime for agricultural and building purposes, brick, and liquid gas. A plant will soon be erected for the production of ammonia, nitric acid, and fertilizers. Gas for city requirements and electric power are also produced to some extent. The company's efforts to bring down production costs to competitive levels have been successful, and shale oil is now produced on a fully competitive basis.

Through the purposeful and skillful endeavors of Swedish technicians, a formerly useless mineral is now an important raw material which provides our country with an invaluable fuel and other important products. The Swedish shale oil industry has attracted much attention and aroused considerable interest all over the world. It is the aim of the company to develop a highly efficient industry despite the poor quality of the Swedish shale which, as far as is known, is lower in oil content than that of all other shales currently utilized commercially.

In the hope of furthering a sound development and exploitation of the world's potential natural resources, and especially of stimulating the work of solving the many problems attending the recovery of oil from shale, we present here a brief description of our works.

SVENSKA SKIFFEROLJE AKTIEBOLAGET
(Swedish Shale Oil Company)

KVARN TORP

History

War Period 1941—45:

The history of the Swedish Shale Oil Company began in 1941 not long after the outbreak of World War II when Sweden's overseas supply lines were severed. In an effort to ensure the meeting of military, industrial and civilian needs from domestic sources, the Swedish Riksdag and Government initiated several development projects including the recovery of oil from shale. Following extensive research and surveying work conducted by a team of geologists, chemists and technicians, the Swedish Shale Oil Company was formed early in 1941. The Government invested a total of 50,700,000 kronor during the initial phase of construction and holds the entire capital stock of the company.

The Swedish Shale Oil Company's plant was built at Kvarntorp in central Sweden where the richest oil shale deposits are located. Work on the project was accelerated because of the extraordinary conditions prevailing during the war, and when the first stage of construction was completed and production got under way in April 1942, the shale oil plant had an annual capacity of 15,000 cubic meters (95,000 bbls). The productive capacity of this plant was expanded in two subsequent stages to a total of 75,000 cubic meters (470,000 bbls) of oil yearly.

Because of the high sulphur content of the shale, the extraction of oil was combined with the production of refined sulphur from the very start. This production largely contributed toward augmenting the short supply of sulphur consumed by the domestic chemical industry. Originally, the productive capacity of the sulphur plant was about 5,000 tons annually but it has since been expanded to approximately 22,000 tons.

Period of Reconstruction—1946—53:

The second period of the company's history began in 1945. When Sweden again had access to foreign sources of crude and refined oils after the war, it soon became apparent that shale oil could not compete in price with imported fuels without Government subsidization of production. As a result, the company drew up a detailed plan to bring down costs to competitive levels. This plan was based on the experiences gained and results achieved in the development work which has been in progress ever since the company was founded. The program, which has been endorsed by the Government, calls for various improvements in oil production methods and the recovery and utilization of several valuable by-products of shale. Its realization requires an additional capital expenditure of 38,000,000 kronor, and the reconstruction work, started in 1946, will be completed by 1953. By then the company's annual production will be as follows:

Crude oil	105,000 cubic meters (660,000 bbls.)
Liquid gas	15,000 tons
Refined sulphur	28,000 ,,
Quicklime	45,000 ,,
Nitrogen fertilizers	100,000 ,,

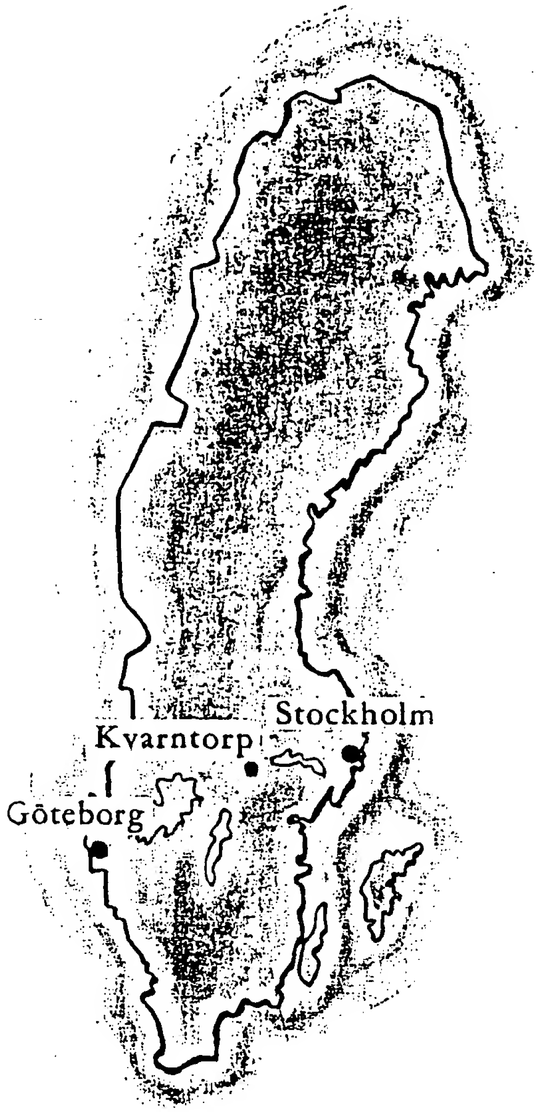


Table 1.

AVERAGE CHEMICAL COMPOSITION OF KVARNTORP SHALE.			
	%		%
Silica	42 —48	Hydrogen	~2
Alumina	12.5—14	Carbon	18
Iron oxide	8 — 9	Sulphur	7
Magnesia	~1	Moisture	1
Lime	~1	Ash	73
Potassium oxide	4	Calorific value	2200 kcal/kg
Sodium oxide	0.5		

Table 2.

FISCHER ASSAY TEST ON KVARNTORP SHALE.	
Oil yield	4— 7 % by weight
Gas yield	40—45 cubic meters per ton
Water	1— 2 % by weight
Coke	85—88 % by weight

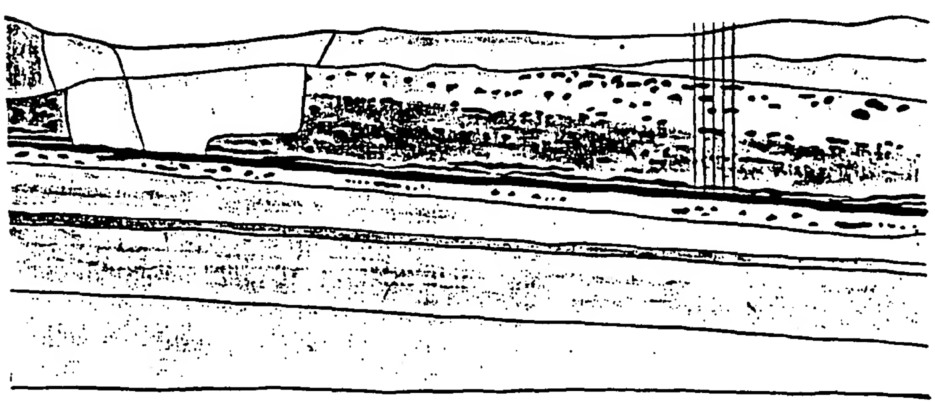


Fig. 2. The shale deposits at Kvarntorp.

After completion of the current reconstruction program, it is planned to expand the small factory which utilizes the spent shale for making building bricks. Further, the liquid gas which is being produced at Kvarntorp has opened the possibilities for the production of several high-grade chemicals, such as solvents, alcohol, plasticizers, detergents, etc. Intensive research into this matter is expected to result in the production of some of these chemicals in commercial quantities.

Future Broadening of Production Program:

The Swedish Shale

Origin:

The principal raw material on which production at Kvarntorp is based is oil shale, a marine sediment which was formed during the Ordovician and Cambrian ages some 400 million years ago. Vegetable debris was carried by streams from inland areas to shallow sea bays and lagoons where it was deposited together with dispersed clay and other inorganic matter, dead algae and sea animals. Thus, a mud was formed which is the parent material of oil shale. In time some changes occurred due to the dissolution of some components, precipitation of, for example, calcium carbonate, and to microbic activity, etc. During geological intervals the mud formed a hard, compact rock—the shale. Because of varying climatic conditions during its formation, the shale consists of thin layers which, to some degree, differ in composition from one another.

Characteristics:

The organic components of the rock are together called *kerogen*. When the shale is heated to a temperature of between 400° and 600° C (750°—1100° F), the kerogen changes chemically into *crude oil*, *crude gas*, and *carbon*. Together with the inorganic components the carbon forms what is called "spent shale" or "shale coke". The oil and gas are similar to crude petroleum and natural gas but differ from them in some respects. Special techniques must therefore be applied in their treatment and refining into marketable products.
The kerogens of different shales give different yields of oil. The Swedish oil shale in the deposits at Kvarntorp give an oil yield of between 4 and 7 percent by weight. An analysis of the Kvarntorp shale is given in Tables 1 and 2.

Swedish Oil Shale Deposits

The richest oil shale deposits in Sweden are located at Kvarntorp in the Närke province. The size of these and other Swedish deposits and their locations by provinces are shown below:

Province	Quantity of Shale (Million Tons)	Oil Yield Percentage	Oil Yield Million Tons
Närke	1,700	5	85
Östergötland	5,000	3.8	190
Västergötland	3,000	1.7	51
Öland	3,000	3.8	84
All Sweden	12,700	—	410

Fig. 3. Mining.

Oil shale is a common mineral and occurs in many countries. So far, few countries have shown a serious, commercial interest in their shale deposits and, consequently, they have been inadequately surveyed. The world's oil reserves in shale are roughly estimated below.

Estimated Oil Shale Reserves of the World:

Country	Oil Content in Million Tons
Australia and Tasmania	8
Brazil	1,625
Bulgaria	30
Burma	1,700
Estonia	700
France	210
Germany	255
Manchuria	33
Russia	5,500
Scotland	100
South Africa	5
Spain	1
Sweden	410
Turkey	3
United States	100,000
Yugoslavia	225
Total reserves	110,805

Mining

As shown in fig. 2 the shale seam consists of two layers, an upper stratum giving an oil yield of about 5 percent, and a lower one giving a yield of from 6 to 7 percent. Each of these two layers is between 7 and 8 meters (20—24 feet) in thickness, both being covered with a layer of limestone. The layers tilt slightly toward the south, outcropping in the northern part of the deposit where the quarry is located. Circular, lens-shaped limestones are intruded in the shale.

Before the shale is mined, the surface soil is removed by a dragline shovel with an action radius of 40 meters (120 feet). The shale is blasted loose with explosive charges whereupon it is loaded by shovels on to cars and hauled by railway to the crushing mill (fig. 3).

Crushing and Screening

The first stage of the crushing is performed by two jaw crushers, whereupon the shale is fed on to a belt conveyor and transported to the separation house where the limestone concretions are picked out by

Fig. 4. Separation of the limestone.

Fig. 5. Storage silos.

KVARN TORP

hand (fig. 4). The coarse shale is crushed further in a Symons' breaker and screened into three different size classes. These are:

0—3	millimeters	(0—1/8"):	the fines (not utilized at present)
3—30	,,	(1/8"—1/4"):	the grain class, most suitable for Kvarntorp retorts
30—70	,,	(1 1/4"—3"):	the grain class for IM and HG retorts

Storage Silos:

The different classes of shale are stored separately in eleven concrete silos with an aggregate capacity of 11,000 tons (fig. 5). From here the shale is carried on belt conveyors to the retorts. The separated limestone is conveyed to the kilns.

A total of about 5,500 tons of crushed shale and limestone is produced daily.

Oil Recovery Methods

When the company's production was planned, the aim was to achieve a maximum yield of oil products with a minimum of capital expenditure, material, labor and time. Among the various methods of recovery existing at the time, the company chose to use the Bergh, IM, and HG retorts, as well as the Ljungström *in situ* method.

Thermal and Material Balances

The main advantage gained in combining the aforementioned recovery methods was the favorable heat balance attained in the plant. The Bergh retorts give a certain amount of surplus heat which is profitably utilized by the IM and HG retorts. The latter retorts require more heat but they give, on the other hand, a higher oil yield. Moreover, as the different methods require different grain sizes, and several sizes are always obtained in the crushing of shale, they supplement one another also in this respect.

The Bergh recovery method also gives a certain amount of electrical energy which is used partly to meet the plant's own power requirements, and partly for heating the shale electrically *in situ* (i.e. in its natural or original position) in accordance with the Ljungström method. The latter method is well adapted for working those deposits which are covered with limestone and thus inaccessible with present mining methods.

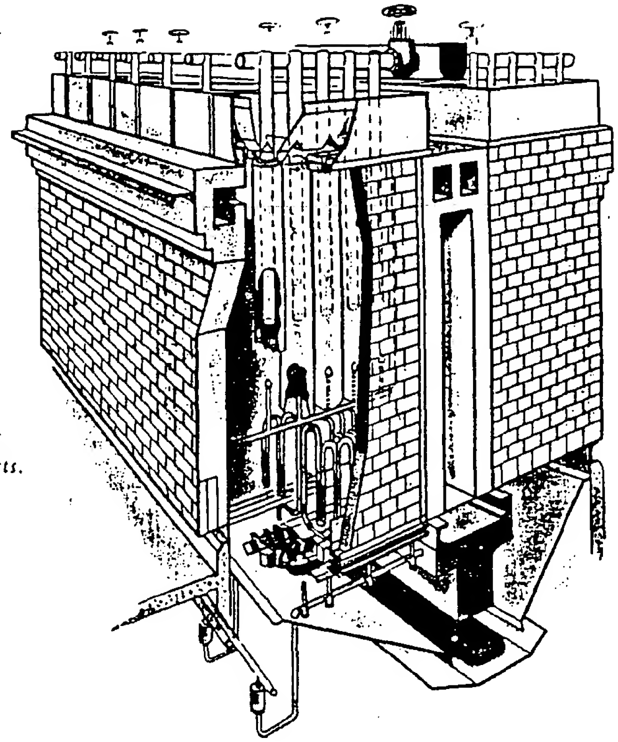


Fig. 6. Block of Kvarntorp retorts.

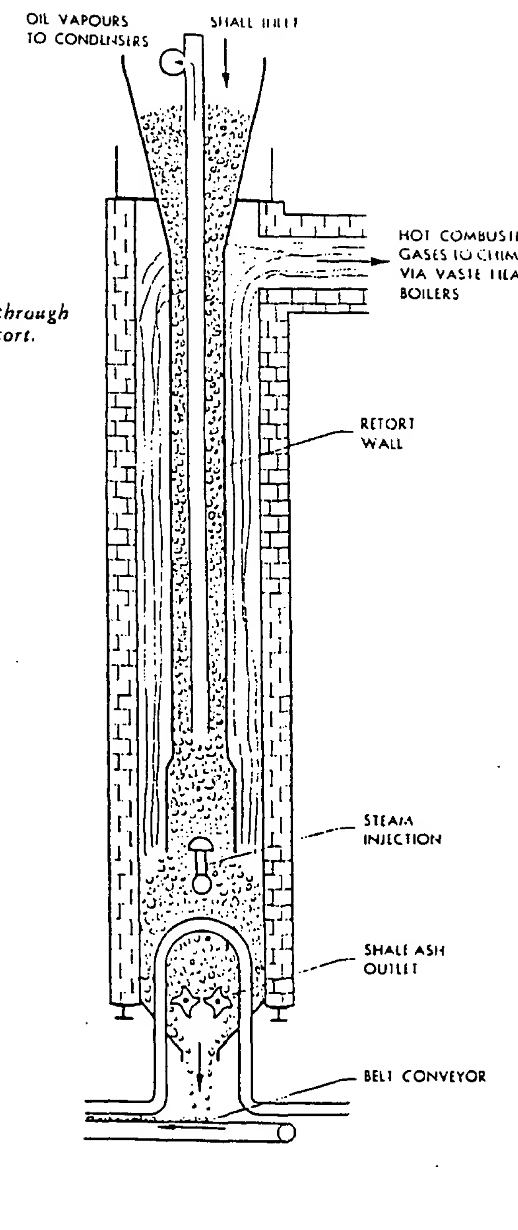


Fig. 7. Section through a Kvarntorp retort.

Fig. 8. The upper part of a Kvarntorp retort house.

The Bergh Recovery Method

This method of oil recovery was invented by Mr. S. V. Bergh shortly after the first World War. The principal feature of the Bergh retort is that the heat value of the shale coke is utilized for pyrolysis, thus eliminating the need for external sources of heat for this purpose.

Although the Bergh retorts originally installed in the company's plant worked satisfactorily, their capacity was limited. Experiences gained in the company's work, however, led to essential improvements which nearly tripled the capacity of each retort. All the Bergh retorts at Kvarntorp have therefore been, or will shortly, be rebuilt in accordance with the so-called modified *Kvarntorp Method*.

The Kvarntorp Retort

The Kvarntorp retort consists of a vertical tube, 20 cm. (8″) in diameter and 3 meters (9′) in height (figs. 6—9). Five retorts are arranged together in a brick-walled chamber or so-called *box*. Fourteen boxes form a block, and from 8 to 12 blocks form a *bench*. The retorts are heated externally by hot flue gases in the chamber. The crushed shale is charged mechanically at the top and passes down through the retort tubes. Preheating takes place in the upper part of the tube, the temperature in the lower end (500°—550° C — 930°—1020° F) being adequate to cause pyrolysis of the shale. The oil vapors are drawn off through suction pipes inserted in the center of each retort and extending into the pyrolytic zone.

Cõke Combustion

The hot shale coke proceeds through the open lower end of the retort where it is ignited by a preheated current of air. The ascending combustion gases emit their heat on the walls of the retort tube, passing on the way to the chimney a waste heat boiler where more heat is recovered as steam.

In order to prevent the mixing of vapors and combustion gases within the pyrolytic zone, a pressure balance is maintained by means of fans. Moreover, a separation zone is created by the charging of steam through a pipe ending some inches above the retort's lower end.

As the melting point of the shale ash is comparatively low (abt. 950° C, 1740° F), the temperature in the combustion zone must be carefully controlled in order to avoid caking of the shale. This is done in accordance with the *Kvarntorp coke combustion method* in which the coke bed is cooled by a series of boiler tubes inserted into it. Some of these tubes function as boilers, others as superheaters. Surplus air blown through the roughly 3 feet thick layer of hot ash also has a cooling effect upon it.

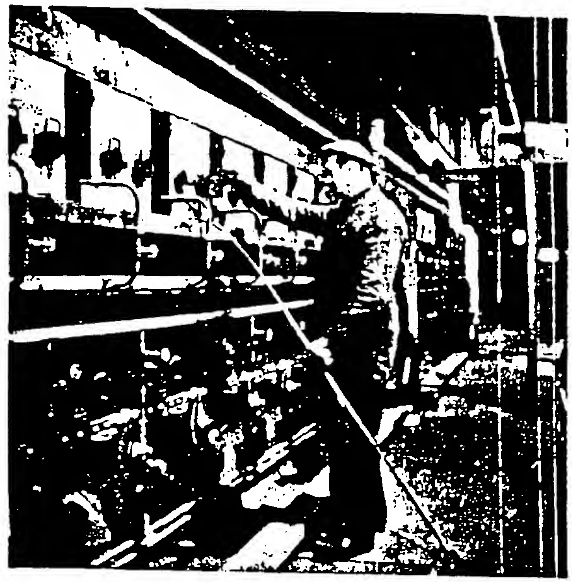


Fig. 9. *View from the interior of the Kvarntorp retort house.*

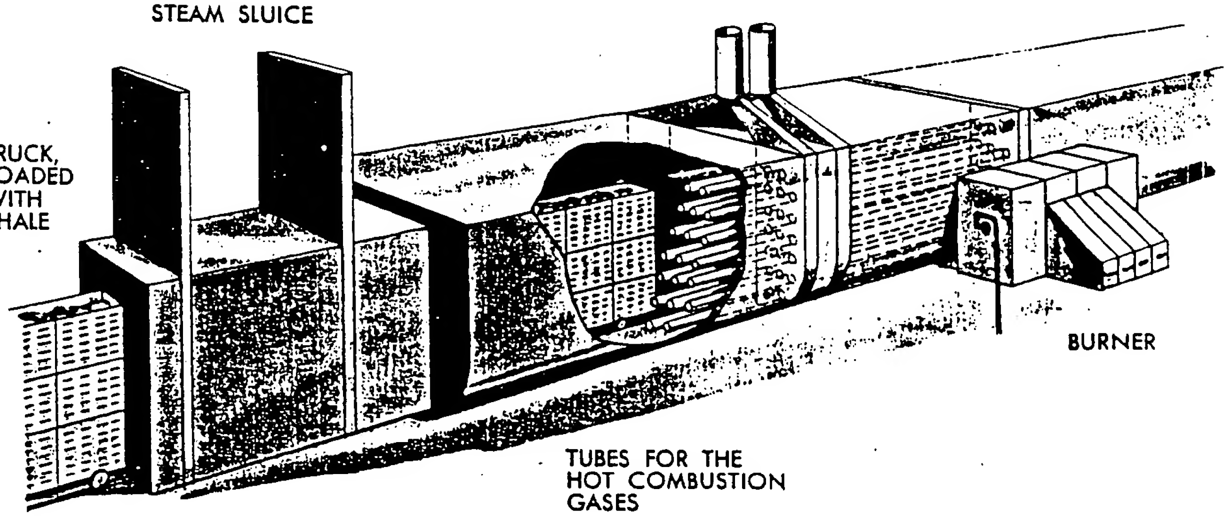


Fig. 10. Principle sketch of the IM oven.

The shale ash is discharged automatically through the bottom of the combustion chamber which is equipped with labyrinths, whereupon it is transported on belt conveyors and dumped on ash piles. The whole process is continuous, each individual retort having a capacity of about one ton of shale a day. At the present time, the company has six benches of Kvarntorp retorts, comprising a total of 3,920 units with an aggregate capacity of 3,500 tons of shale a day.

The Kvarntorp retort produces from one ton of Swedish oil shale of average grade:

Crude oil	abt.	45 liters (12 U.S. gals.)
Crude gas	,,	55 cu.m. (1950 cu.ft.)
Steam		32 atm. 375 C, 470 lbs./sq.in., 700° F

The IM Retort

The IM retort was designed by Mr. F. Carlsson (Industrial Methods, Ltd., from which the abbreviation was derived) and originally was used in Estonia with satisfactory results. It consists of a roughly 60 meter (200 ft.) long horizontal, circular tunnel with a diameter of 4 meters (12 ft.). The shale is conveyed through the retort in perforated cast-iron trucks, 2.5 m.×2.5 m×0.5 m. (8'×8'×1.5') in size, each capable of carrying about 2.8 tons of shale. The retort accommodates 24 trucks at a time. In order to keep out air and to prevent gas leakage during charging and discharging operations, the tunnel ends are equipped with steam locks (fig. 10).

The heat required for pyrolysis is generated in three oil- or gas-fired burners located beside the tunnel, the hot combustion gases passing through tubes running parallel with it. The heating tubes are arranged in three sections with series of increasing temperatures for the shale to pass (abt. 350° C, 450° C, and 550° C or 660° F, 840° F, and 1020° F, respectively). In order to increase the heat transfer, the oil gases formed in the tunnel are blown through the perforated shale trucks by fans on top of the retort. Part of the oil gases is continuously drawn off and condensed in the condensation plant. The flue gas heat is recovered in a waste heat boiler.

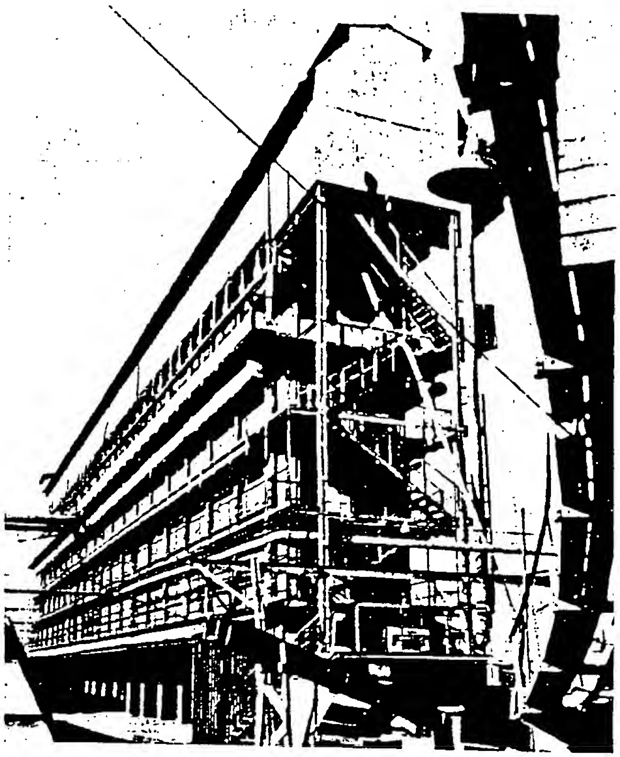


Fig. 12. *Exterior of the bench of HG retorts.*

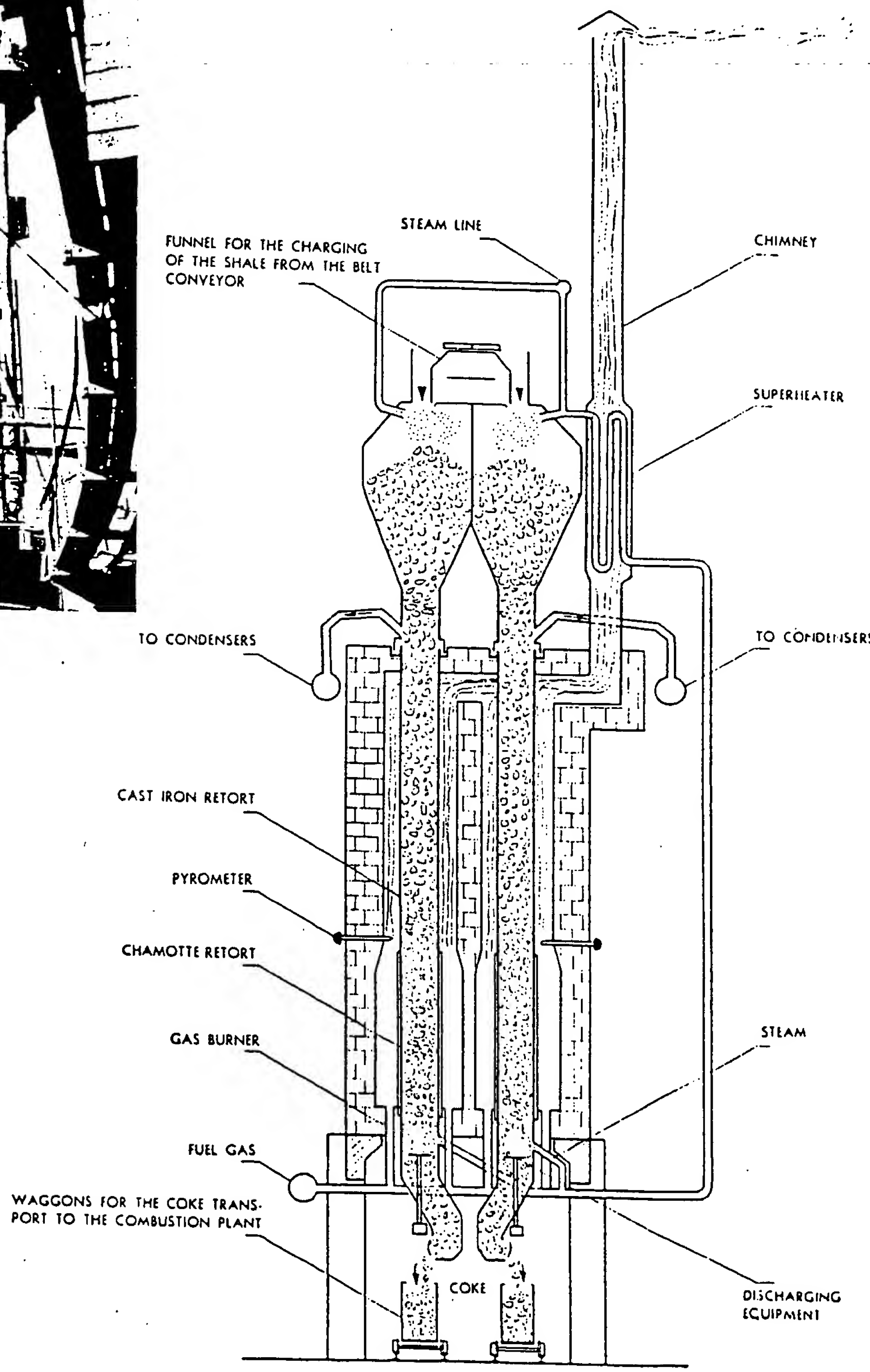


Fig. 11. *Section through an HG retort.*

The shale trucks are pushed through the tunnel of the retort, this action being continuous. The shale coke is discharged through the truck's bottom and transported to a separate coke combustion plant. There are two IM retorts at the Kvarntorp plant, each with a capacity of 650 tons of oil shale a day.

The HG Retort

The HG (or Rockesholm) retort is a modified Scottish retort designed for Swedish conditions by Messrs. Hultman and Gustafsson, hence the abbreviation HG. It is a vertical, cylindrical retort, 0.7 meter (2 ft.) in diameter, and 9 meters (27 ft.) in height (fig. 11). The upper part is of cast iron, and the lower, somewhat wider part, is of refractory brick. The shale is charged through the upper steam trap, moves slowly down the retort and is discharged through the steam trap at the lower end. The retort is heated by a gas burner in a combustion chamber located outside. Superheated steam is admitted at the retort's lower end in order to increase the oil yield and, especially, the gas yield. The temperature maintained in this retort is sufficient to permit the formation of water gas through a partial reaction between the steam and shale coke.

The oil gases are drawn off near the retort's upper end and are condensed in water-cooled tubular condensers. The high temperature maintained during pyrolysis frees some of the nitrogen in the shale in the form of ammonia which is recovered from the condensed pyrolysis water as ammonium sulphate. The discharged shale coke is hauled by truck to the coke combustion plant.

There is one bench of HG retorts at Kvarntorp consisting of 72 individual units with an aggregate capacity of 800 tons of shale a day (fig. 12).

Condensation

The various retort units are furnished with separate condensation facilities. The cooling and condensation of oil vapors is carried out either in tubular cold water coolers or by washing with cold oil which, in turn, is chilled with water.

The pyrolysis vapors (fig. 13) contain some water (moisture and water obtained through chemical reaction during pyrolysis) which is condensed together with the oil and separated from it by settling in cylindrical tanks. The crude oil is pumped to the refinery. The pyrolysis water is de-oiled and purified before going to the drain. The uncondensable gases are despatched to a gas holder.

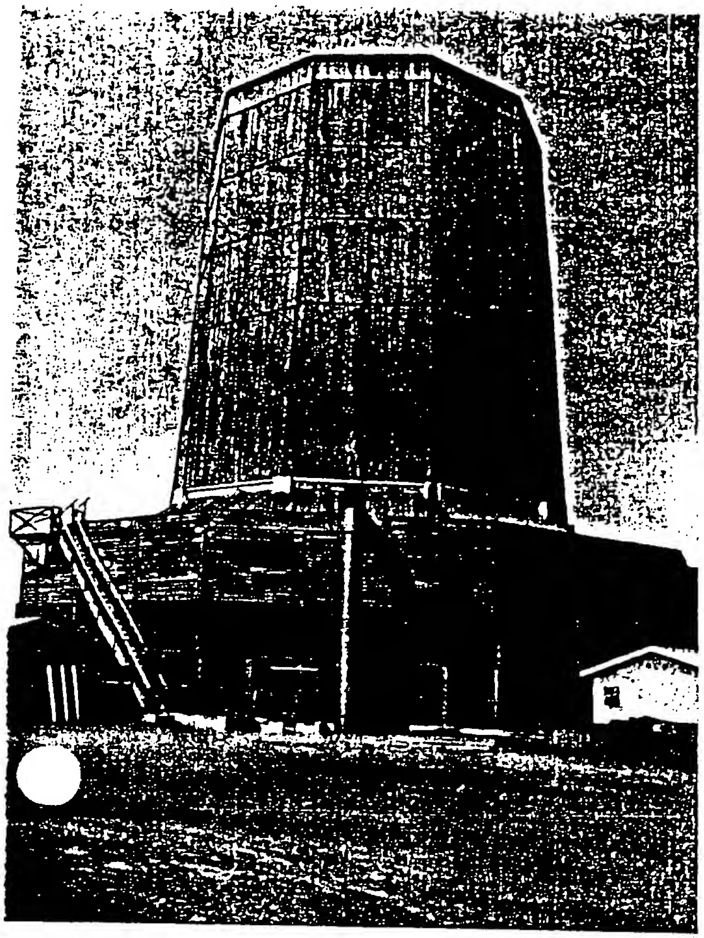


Fig. 14. Interior of a condensation plant.

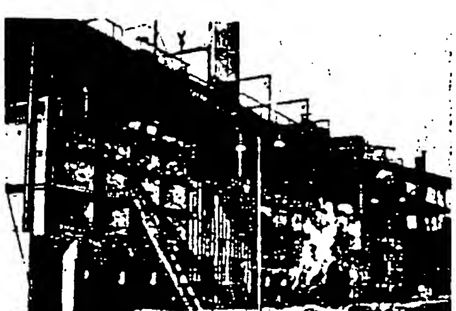


Fig. 16. Exterior of the coke combustion plant.

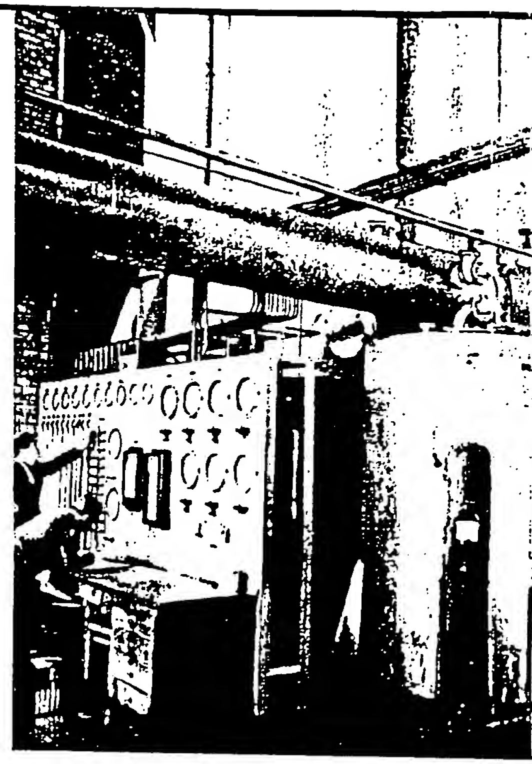


Fig. 13. Cooling tower for water.

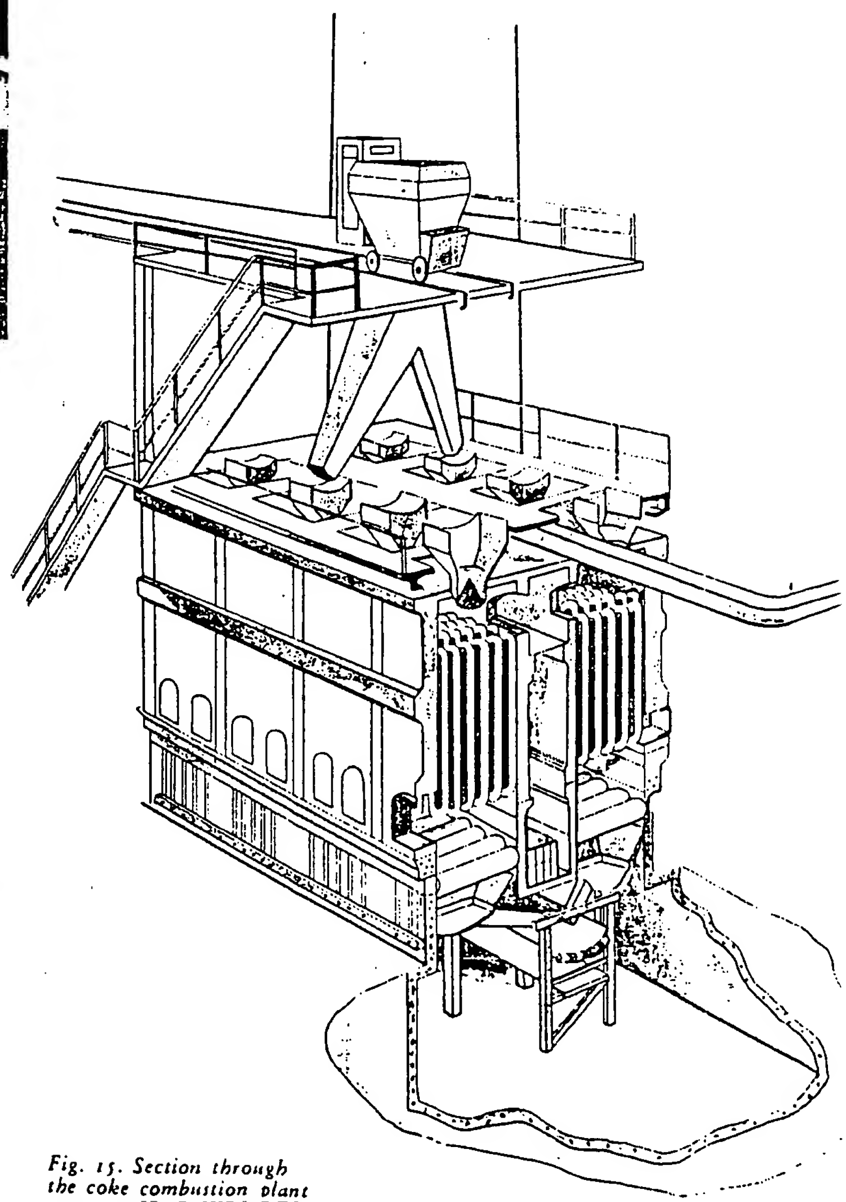


Fig. 15. Section through the coke combustion plant

The water supply of the Kvarntorp plant is obtained from Lake Tisaren through an 18 kilometer (11 mile) long, wooden pipeline about half a meter (20 in.) in diameter. The bulk of the water used in condensing operations is recooled and recirculated (fig. 14).

The Coke Combustion Plant

As previously mentioned, the shale coke from two of the retort systems (IM and HG) is not directly utilized. This coke has unfavorable pyrophoric qualities which preclude its dumping on dump piles. Following the development of the Kvarntorp coke combustion method, it is is now utilized for combustion and steam generation, the separate coke combustion unit receiving the coke discharged from the IM and HG retorts. This unit operates on the same principle as that of the Kvarntorp retort, the hot coke being charged into vertical shafts where it is ignited by a hot, ascending current of air. The combustion heat is absorbed by a series of vertical boiler tubes equipped with a water-pump circulation system. These tubes simultaneously cool the combustion zone to a temperature immediately below the melting point of the shale ash (950° C — 1740° F). Some of the tubes serve as superheaters (figs. 15 and 16). The shale ash moves slowly down the shaft and is discharged automatically on to conveyors.

The steam produced is delivered as superheated steam of 30 atm. (440 lbs./sq. in.) pressure to the steam power plant. About 1,200 tons of superheated steam are produced daily.

Steam Power Plant

The steam generated in the Kvarntorp retorts and in the coke combustion unit is collected in the power plant's steam domes together with the steam from three boilers fired with the surplus pyrolysis gases. Steam is required for several purposes at the Kvarntorp plant, such as for refining operations, sulphur recovery, liquid-gas production, and for the manufacture of fertilizers. The process steam is distributed in a network for high, medium, and low pressure steam (23, 10 and 2.5 atm., 335, 150 and 36 lbs./sq.in.).

The power plant also houses three STAL steam turbines connected to electrical generators with a total generating capacity of 28,000 kw. This plant also serves as a control and switchboard central for the distribution of power to the various units (fig. 17). The electric power

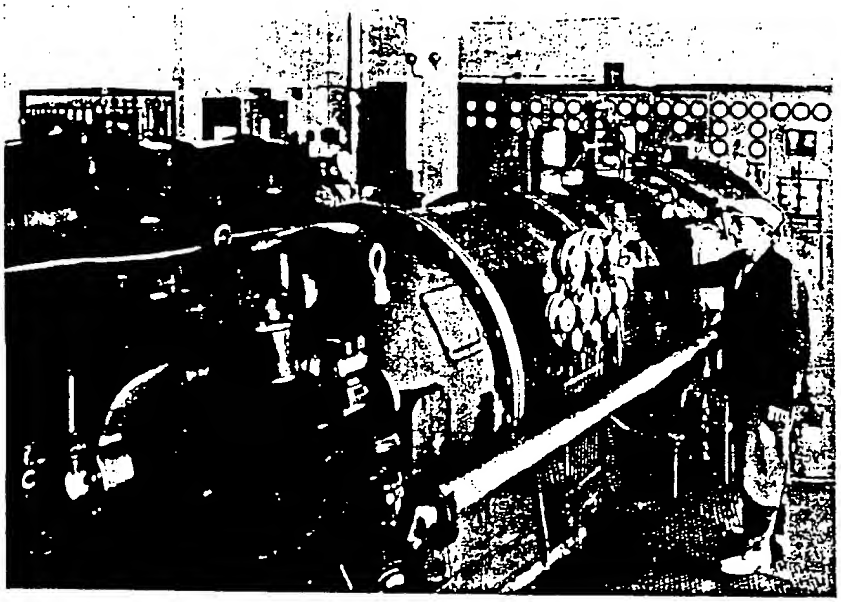


Fig. 17. Steam turbine with generator for steam power production.

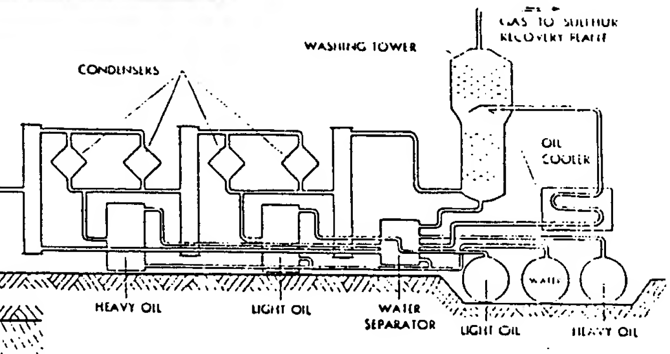
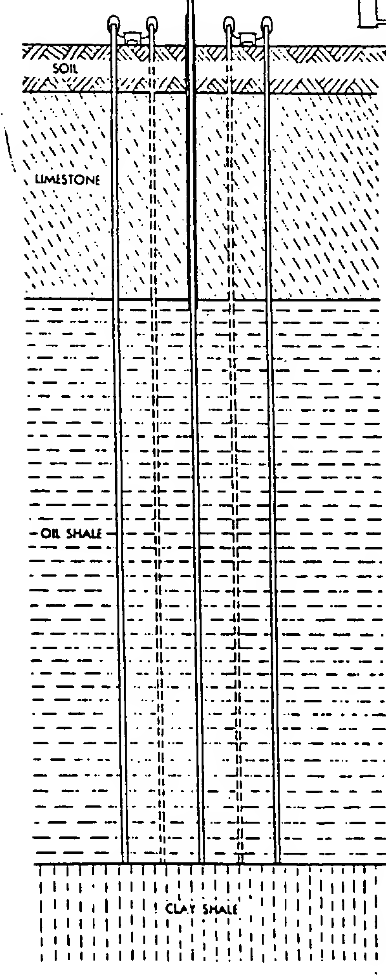



Fig. 18. Principal plan of the Ljungström method.

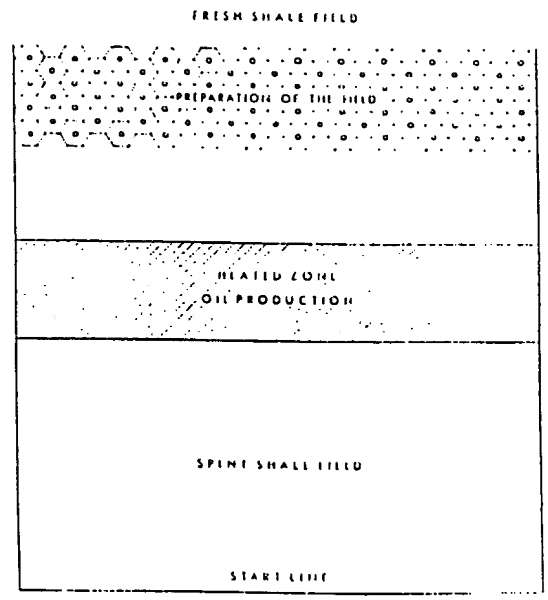


Fig. 19. Plan for working up a Ljungström field.

is distributed in voltages of 6,000 V and 380 V, consumption totaling approximately:

5,500 kw. for the main plants

7,000 kw. for the nitrogen plant

14,000 kw. to 24,000 kw. for the Ljungström plant.

Ljüngström Plant

The Ljungström method of oil recovery was invented by *Dr. Fredrik Ljungström* in 1940 and is based on the principle of electrothermal heating of the shale *in situ*, i.e. without first mining it. The oil vapors are collected in a system of evacuation wells.

Field Preparation

The application of the Ljungström method requires a gas-tight head of some material, a condition which is present in those parts of the deposits at Kvarntorp which are covered with limestone. The field is prepared by draining off the ground water and drilling holes for heating and gas evacuation. The holes are arranged in a hexagonal pattern covering the entire field. The electrical heating elements are placed in the corner holes, the gas holes being located in the centers of the hexagons. The distance between the holes is 2.64 meters (8 ft.) (figs. 18 and 19).

The heating elements consist of corrugated ribbons of chrome steel inserted in 2-inch diameter iron tubes and insulated from the tube walls by quartz sand. The gas holes are drilled to the bottom of the shale seam but are lined only through the gas-tight head. The gas holes are connected to a gas-pipe network above ground.

Power Supply

The electric power for *in situ* heating of the shale is supplied by the company's own steam power plant as well as by public power lines. The high-voltage current is converted in two steps to 152 V, which is the usual element voltage. The second step is performed by mobile field transformers (fig. 20). The amount of energy delivered to the Ljungström plant varies in proportion to the available power supply, normal deliveries amounting at present to between 20,000 and 24,000 kw.

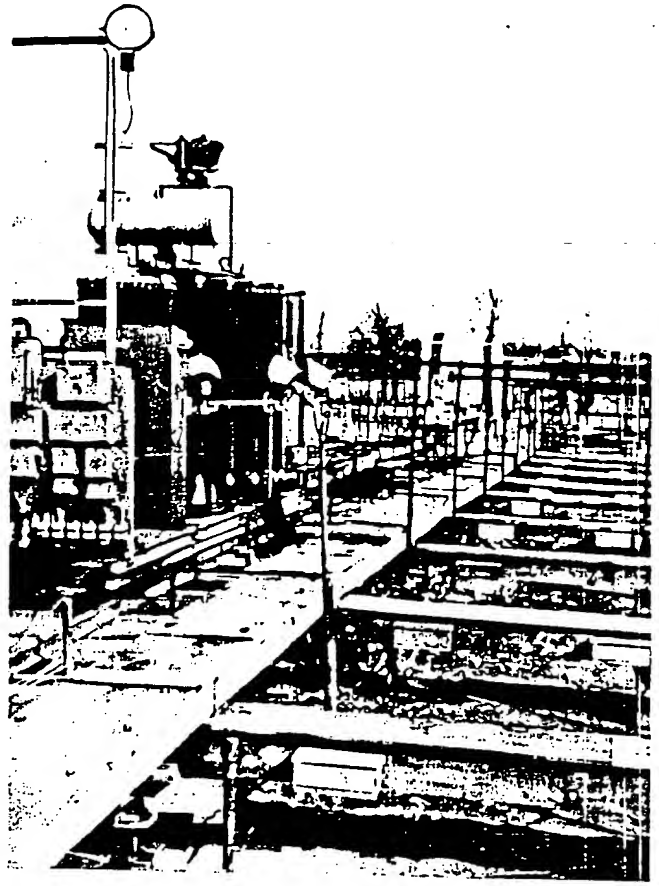


Fig. 20. Mobile field transformer, supply cables and gas-collecting tubes.

Fig. 21. Condensers.

The heating period lasts from four to five months. During the first three months the shale is preheated to a temperature of about 280° C (550° F), the temperature being raised during the remaining months to about 400° C (760° F). During this period and a short time thereafter, the shale gives off oil and gas vapors which seep between the laminae of the shale and proceed toward the gas holes. A slight overpressure created through the formation of oil and gas is sufficient to lift the vapors through the tube system, to the condensers, and to the oil tanks and gas holders.

Heating

As one part of the field is worked, another section is heated. A tremendous heat wave thus passes through the shale seam at a speed of about 140 meters (470 ft.) a year. The width of the field is 180 meters (600 ft.). A total of about 2,000 heating elements operate at a time.

The oil vapors are condensed in specially designed, air-cooled condensers (fig 21). The oil and the uncondensable gases are piped to the refinery and gas holder.

The amount of electric power required is in proportion to the quantity of shale heated and not to its oil yield. Hence, the richer the shale, the smaller the power consumption per unit of produced oil. Power consumption also varies according to the size of the field. The larger the field, the smaller the heat and oil losses.

The production per sq. meter and sq. feet of field area averages:

	Per sq. meter	Per sq. feet
Gasoline	515 liters	12.7 gals.
Kerosene	160 liters	3.9 gals.
Fuel oil	350 liters	8.6 gals.
Liquid propane and butane	80 kilograms	16.4 lbs.
Washed gas	650 cu.meters	2,800 cu.ft.
Sulphur	320 kilograms	65.5 lbs.
Ammonia	8 kilograms	1.6 lbs.

A field area of 25,000 sq.meters (270,000 sq.ft.), corresponding to about 875,000 tons of shale, is worked each year.

Refining

Topping

The crude oil is steam distilled in a topping still into two fractions, a light oil boiling at between 10° C and 200° C (+50° F — 390° F), and a heavy oil fraction boiling at above 200° C (390° F).

Chemical Treatment

Because of the high sulphur content of the Swedish shales, the crude oil derived therefrom is also high in sulphur. The light fraction, the *crude gasoline*, contains about 2 percent sulphur. The sulphur, and the

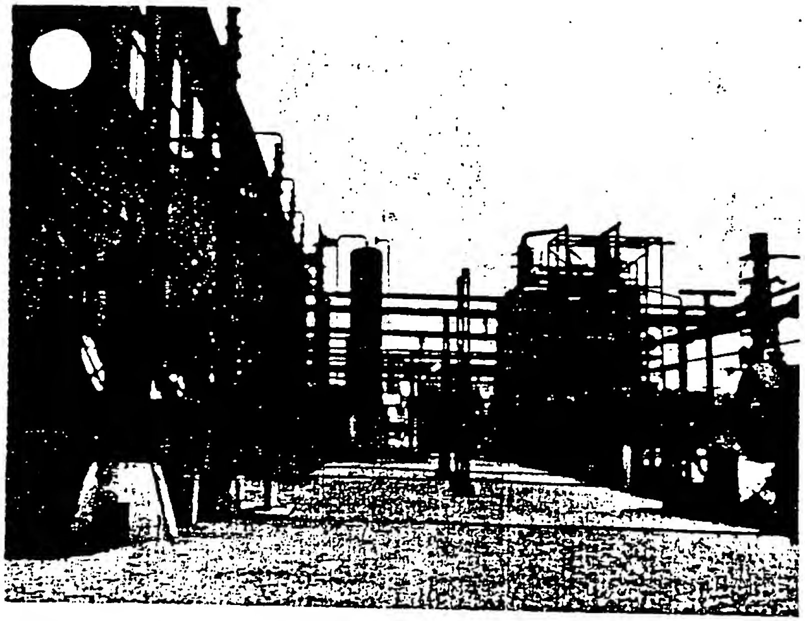


Fig. 22. The refinery.

Table 3.

SPECIFICATIONS FOR GASOLINES.	Regular grade	High grade
	(CFR, Research)	
Color (Lovibond)		
Corrosion (ASTM)	15—25	
Distillation (ASTM)	none	
initial boiling point	40°C	
5 %	50	
15 %	75	
50 %	125	
end point	200	
yield	>96 %	
Vapor pressure (ASTM)	0.5 kg/cm²	
Sulphur	<0.2 % by weight	
Doctor test	sweet	
Tetraethyl lead, %	0	0.06
Octane number	70—72	75—78

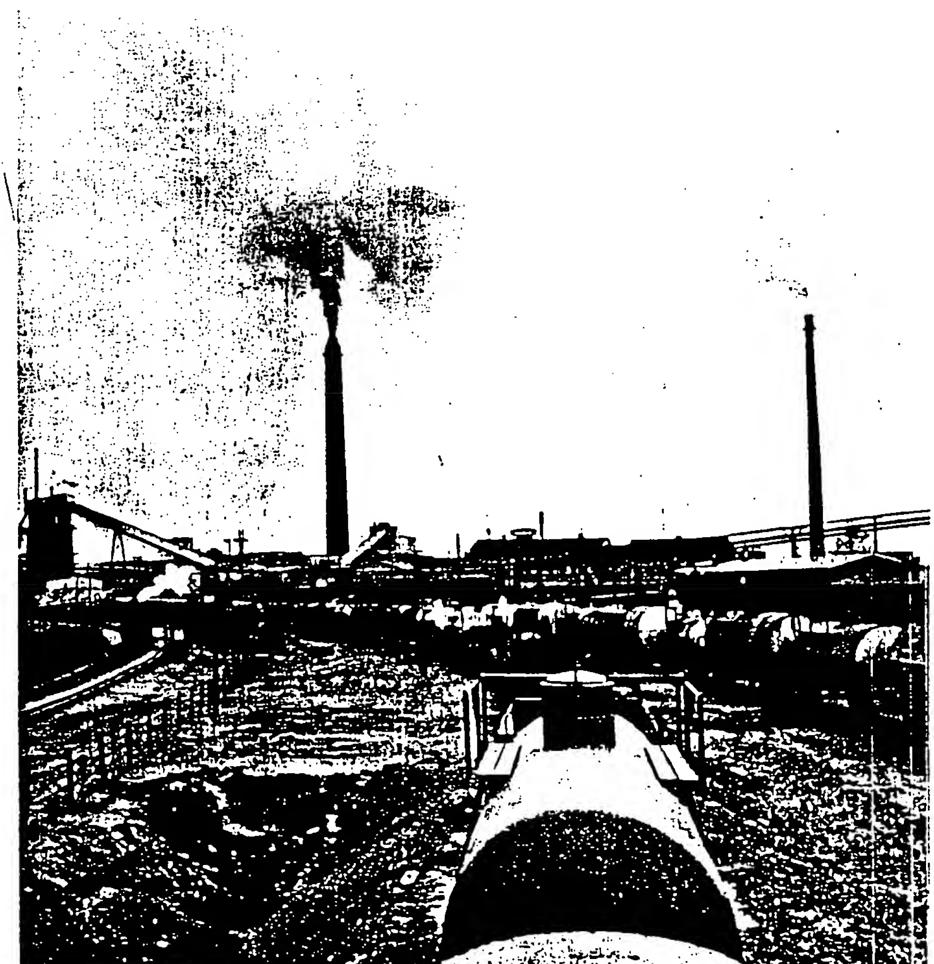


Fig. 23. Railway transport of oil.

discoloring and gum forming substances are removed to meet commercial specifications. This is partly performed by treating the stock with caustic soda and concentrated sulphuric acid in several stages (fig. 22). Finally, the gasoline is treated with a solution of caustic soda in methanol, which removes traces of carbon disulphide, and fractionated (partly under vacuum) into different commercial grades. Two gasoline qualities are produced: the regular and premium grades, the latter leaded.

Fuel Oil:

The heavy oil fraction requires no further treatment after topping and is marketed as a medium-grade fuel oil. The topped Ljungström crude oil, on the other hand, is a light fuel oil used for domestic heating purposes.

New Refining Methods:

At the present time, research is concentrated on two important refinery problems, viz. catalytic desulphurization of gasoline to replace present chemical treatment, and the cracking of fuel oil into more valuable products.

Distribution:

The company maintains its own distribution organization (fig. 23).

By-product Recovery from Gas

Sulphur Recovery:

The uncondensable gases from the different retorts are collected in a gas holder from where they are blown to the sulphur recovery plant (fig. 24). This plant consists of four complete units with a total annual capacity of some 30,000 tons. The gas is washed with a special liquid that selectively dissolves the hydrogen sulphide, amounting to about 20 percent (by volume) of the crude gas. The dissolved hydrogen sulphide is drawn off by heating the solution, and through partial combustion and catalytic action the hydrogen is removed as water. The elemental sulphur is obtained in liquid form and pumped to concrete basins for solidification. Part of the sulphur production is marketed as a granulated product. By 1952—53, the production of sulphur of high quality will total some 28,000 tons annually.

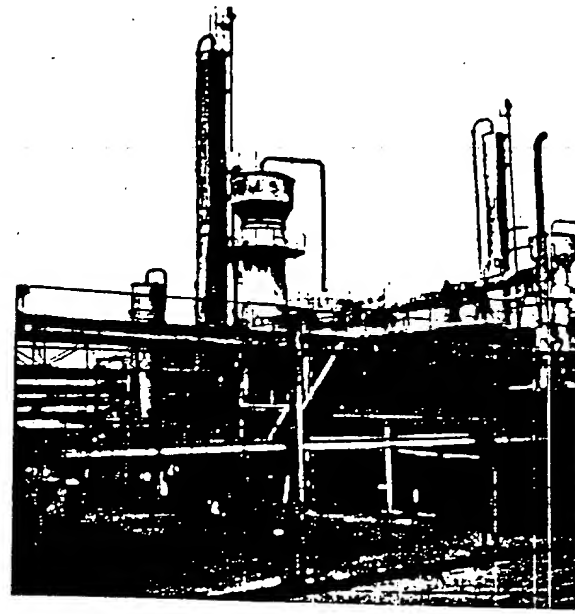


Fig. 24. Part of the sulphur recovery plant.

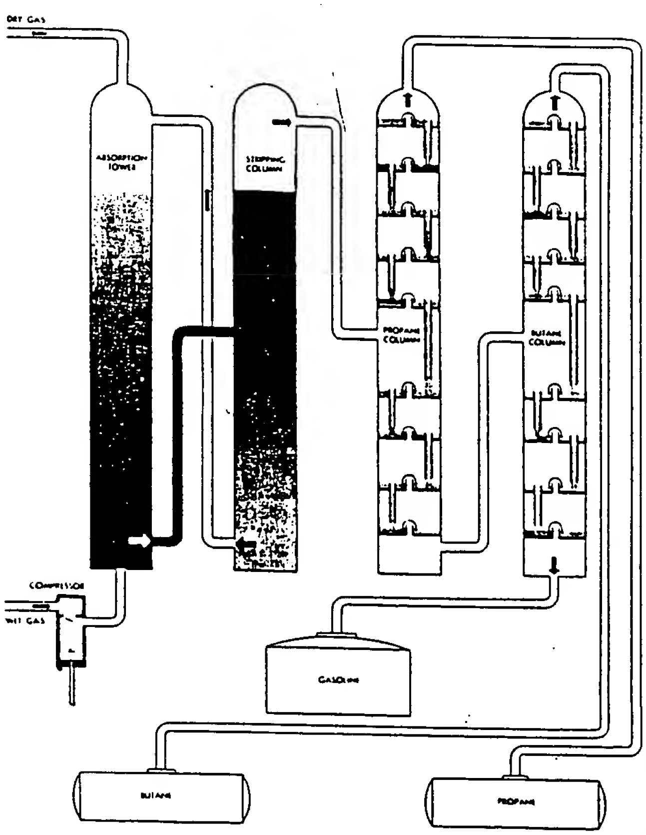


Fig. 25. Principle sketch of LPG recovery.

Fig. 26. Filling LPG containers.

KVARN TORP

Liquid Gas Plant:

After treatment in the sulphur plant, the gas proceeds to a gas absorbtion plant where it is processed under high-pressure conditions (18 atm., 265 lbs./sq.in.), yielding propane, butane, and heavier hydrocarbons (fig. 25). The liquid propane and butane are marketed by the company under the trade name "Gasol" which is used for domestic and industrial purposes (fig. 26). The heavier hydrocarbons form a light gasoline which is refined together with the crude oil.

Nitrogen Plant:

During the initial phase of the company's existence, the surplus gas from the retorts was used as fuel for steam power production. For some time the gas was also piped to the adjacent city of Örebro where it was used for household and industrial purposes. Because the expansion of oil production capacity increased the amount of surplus gas to more than 10,000 cu.m. (350,000 cu.ft.) per hour, the company investigated the possibilities of profitably utilizing it. A decision was subsequently reached to build an ammonia synthesis plant, the construction of which will be commenced as soon as the Government has endorsed the project.

Synthesis Gas:

For the ammonia synthesis, a pure mixture of hydrogen and nitrogen in the ratio 3:1 is required. This gas will be prepared in a plant operating as shown in fig. 27. The shale gas hydrocarbons react in a gas cracker with steam, forming hydrogen and carbon monoxide. The latter is catalytically converted in the presence of steam to carbon dioxide and more hydrogen. The carbon dioxide is removed by washing the gas with water under pressure, whereafter the final purifying takes place in a copper-solution unit. Finally, the synthesis gas is compressed to 325 atm. (4,500—5,000 lbs./sq.in.). (fig. 28.)

Ammonia Synthesis:

The compressed gas mixture reacts to ammonia in pressure vessels over a catalyzer. The ammonia is separated from unreacted gases and cooled to liquefaction. The unreacted gases are recirculated.

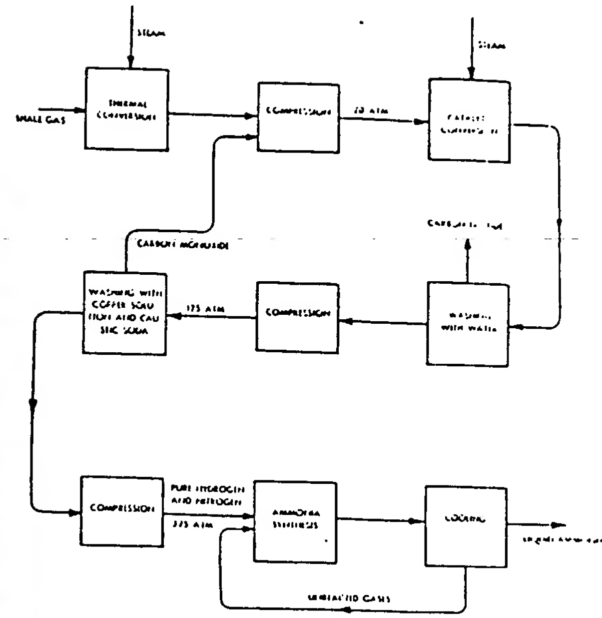


Fig. 27. Principle sketch of ammonia synthesis.

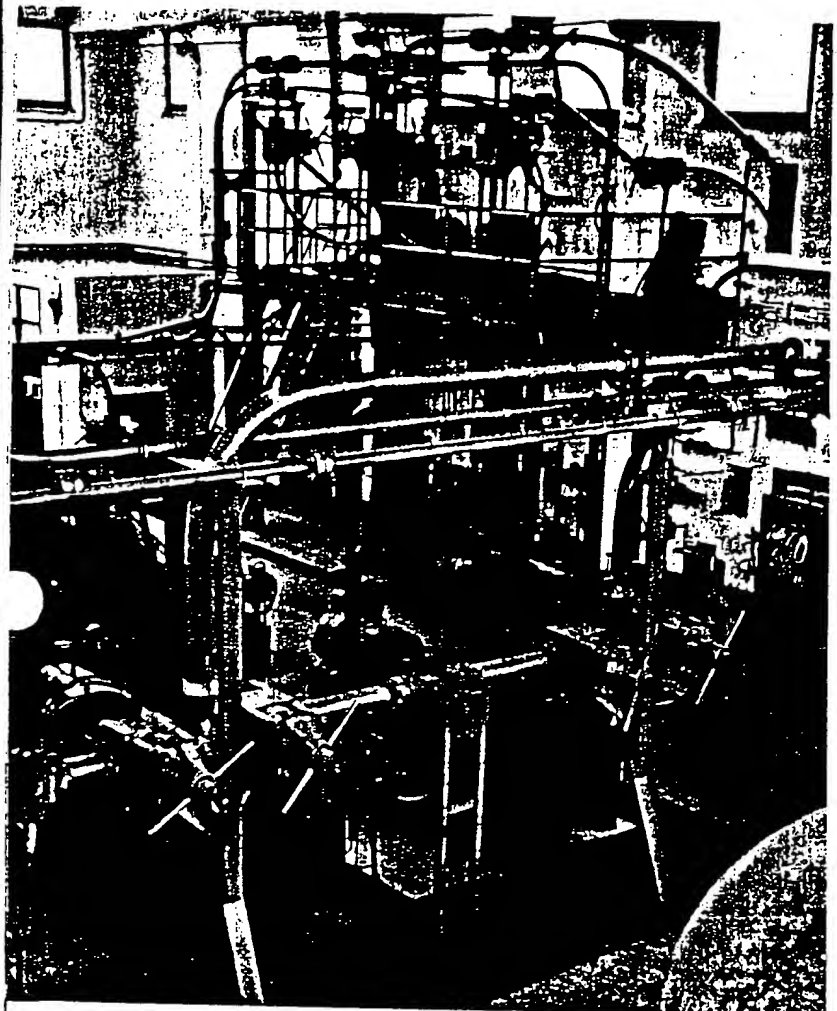


Fig. 28. High pressure equipment for ammonia synthesis.

Fig. 29. Reaction vessels for oxidation of ammonia to nitric oxide.

It is planned to use the ammonia which is produced for fertilizer production, primarily calcium nitrate. For this purpose the ammonia is first converted to nitric acid through oxidation. The gasified ammonia is mixed with air and burned in five combustion vessels containing platinum as a catalyzer (fig. 29). Nitric oxide is thereby formed, giving nitric acid when dissolved in water. This takes place in stainless-steel towers.

Nitric Acid:

The nitric acid is neutralized with limestone and the solution is evaporated and crystallized. The nitrate is dried and crushed to grains, whereupon it is stored in a storehouse with a capacity of about 25,000 tons. The calcium nitrate holds 15.5 percent nitrogen. Agricultural research stations in Sweden have found that this product, as a rule, is superior to others except for special purposes requiring ammonium sulphate, sodium nitrate, etc. Small quantities of ammonium sulphate are also produced at Kvarntorp.

Calcium Nitrate:

The limestone which is picked out from the mined shale is burned in three gas-fired shaft ovens (fig. 30) to produce quicklime for agricultural and building purposes. The annual production of quicklime is some 45,000 tons.

Lime Kilns

The shale ash has good hydraulic properties, making it a suitable base for building materials of various kinds. Although Sweden has for years been making light concrete from shale ash and the Kvarntorp ash is also suited for this purpose, the Swedish Shale Oil Company chose instead to produce a new type of brick. The shale ash is ground and mixed with water, quicklime and certain chemicals so that it forms a pulp-like mass which is molded into blocks. After short autoclaving with steam the blocks harden, giving a brick with good mechanical and thermal properties.

Research into this entirely new product has been in progress for several years for the purpose of ascertaining the material's aging properties, this being an essential requirement for a good building material. Favorable results have been obtained and it is planned to expand the present small productive capacity of the brick plant.

Brick Manufacture

The Kvarntorp works are equipped with warehouses and electrical and mechanical workshops, as well as repair shops for trucks and railway rolling stock and equipment.

Storage and Repair Facilities

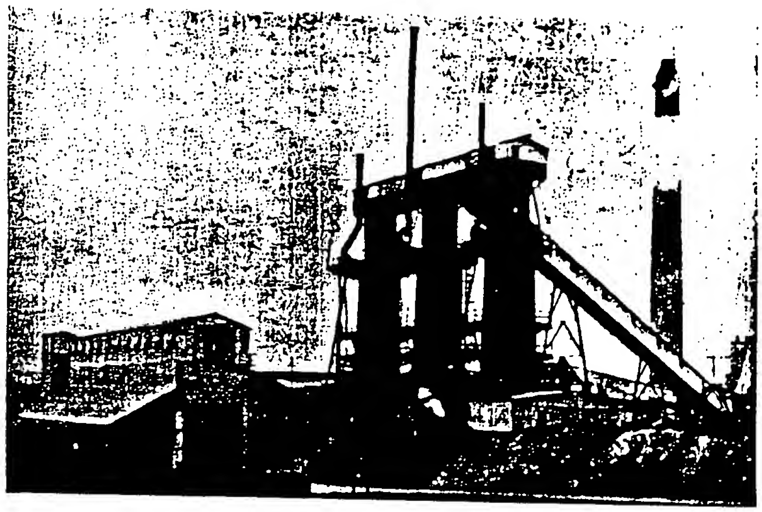


Fig. 30. Lime kilns.

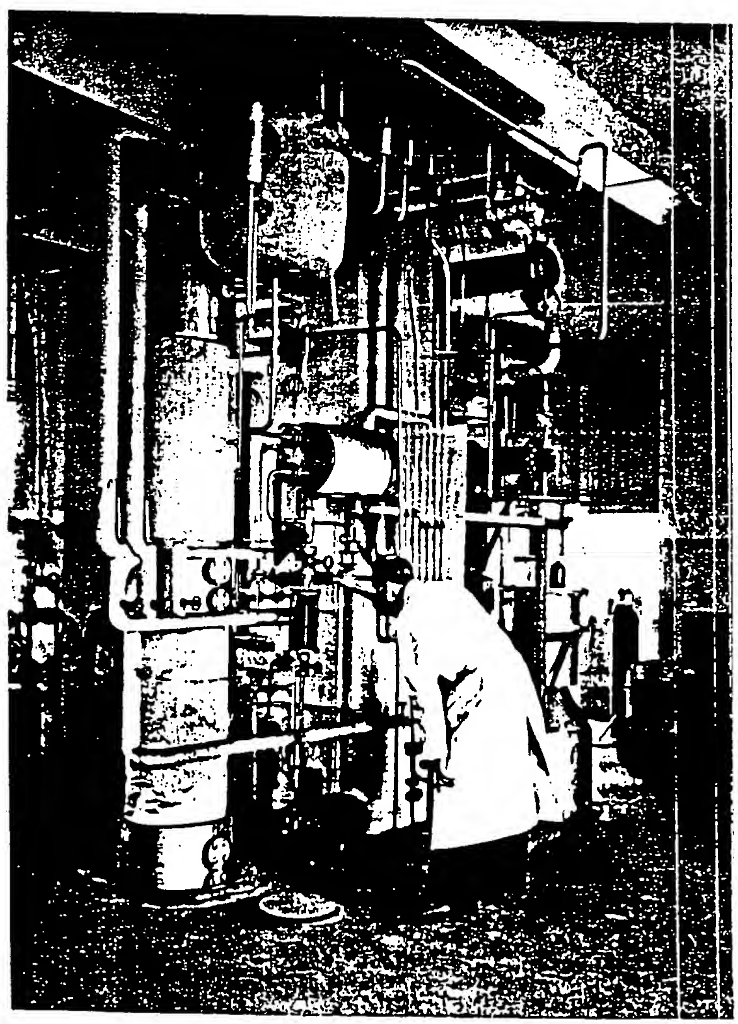


Fig. 31. Part of the laboratory.

Research

Intensive research is carried on in the laboratories at Kvarntorp (fig. 31). New methods and products have been developed in an effort to attain the most economic utilization of the shale and crude products derived therefrom. Special problems are encountered in refining operations and in the recovery of by-products due to the somewhat different composition of crude shale oil as compared with petroleum, especially its higher contents of unsaturated hydrocarbons and special sulphur compounds. As previously mentioned, most of the various processes now employed at Kvarntorp are based on the results of the company's own research and development activities.

The Research Department is organized along the following lines:

Pyrolysis research (composition and retorting of shale)

Gas and oil laboratories (composition and utilization of gas and oil)

Inorganic laboratories (composition and utilization of shale ash)

Control laboratories (analysis methods; routine product control).

Welfare

Due to the presence of inflammable substances in most parts of the Kvarntorp plant, there is a constant fire hazard. Great emphasis, therefore, is laid on fire protection. The plant has its own *fire brigade* with the most up-to-date equipment.

Because of the nature of the work at Kvarntorp and the absence of trained personnel at the time operations were started, there was a potential danger of mechanical and chemical accidents. A *Safety Department* employing qualified personnel was therefore quickly organized. All dangerous points of the plant are now equipped with safety devices and, should an accident occur, first aid may be received in a dispensary by a trained attendant. Modern wash and rest rooms, showers, and individual lockers for the workmen's street clothes are available to employees, as well as canteens where hot meals are served (fig. 32).

The company has built for its supervising personnel, repair men, etc, a little "village" adjacent to the works. This village can boast of a community center with school, library, stores, restaurant, assembly rooms, bath, and athletic fields, among other things.

The employees of the Kvarntorp plant number about 1,000 and the Ljungström plant about 100. When completed, the nitrogen plant will employ about 200.

Head Office

The head office of the company is located in the city of Örebro, about 20 kilometers from Kvarntorp. The company's address is: Svenska Skifferolje Aktiebolaget, Drottninggatan 3, Örebro, Sweden.

Staff

At present the company's staff includes:

Mr. Claes Gejrot, President

Mr. Hans Grebius, Chief Engineer

Mr. Arvid Johansson, Chief Engineer

Mr. Edmund Schjånberg, Research Director

Mr. Åke Tydén, Attorney

Mr. Hans Wiborgh, Sales Director

Board of Directors:

Mr. J. H. Qvistgaard, Director General of the National Commission for Economic Defense, Stockholm. Chairman of Board.

Mr. Erik Brandt, Stockholm

Mr. Claes Gejrot, Örebro

Mr. Gunnar Mohlne, Stockholm

Mr. C. W. Pilo, Stockholm

Mr. Donovan Werner, Stockholm

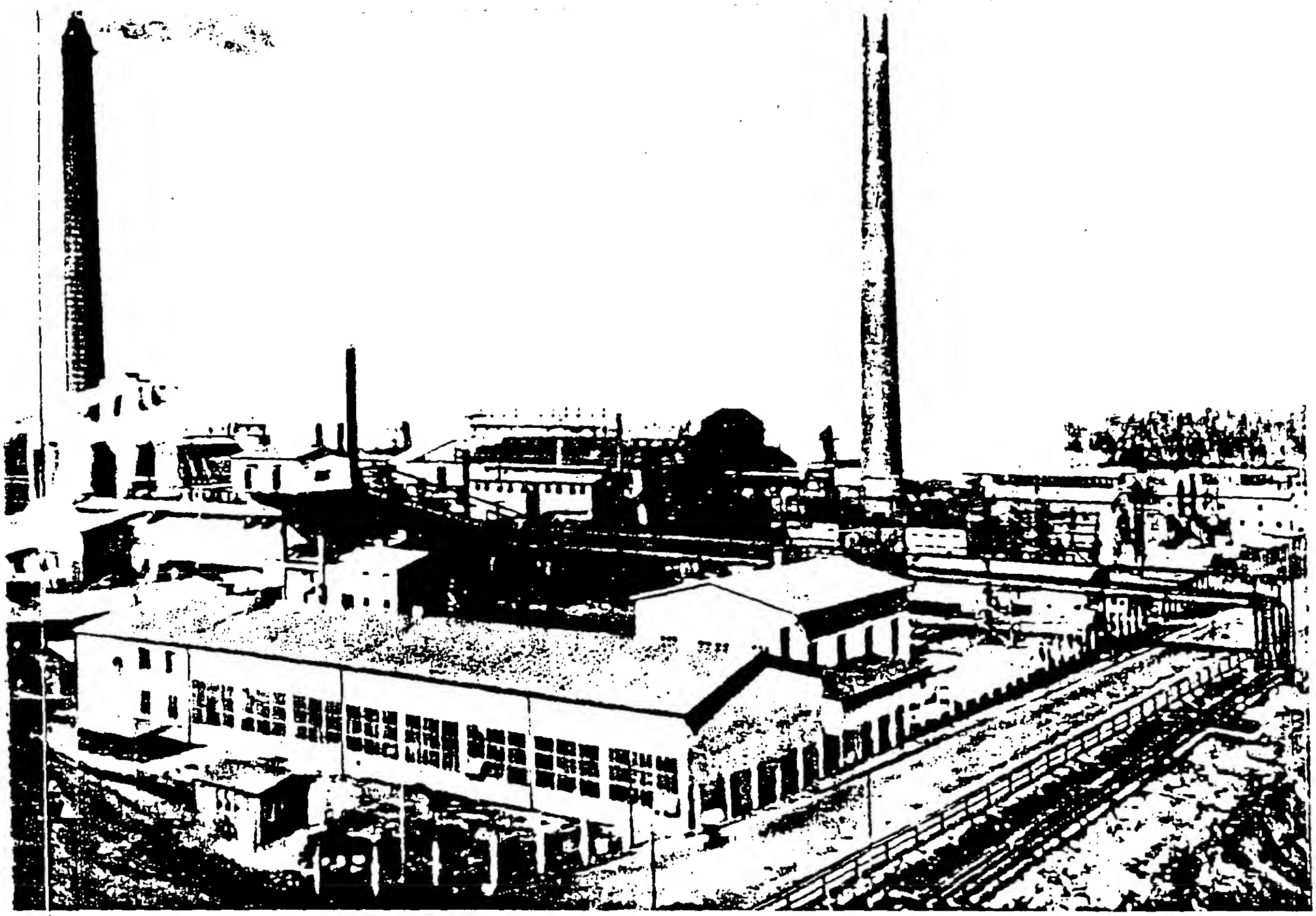
Mr. Torsten Åqvist, Örebro

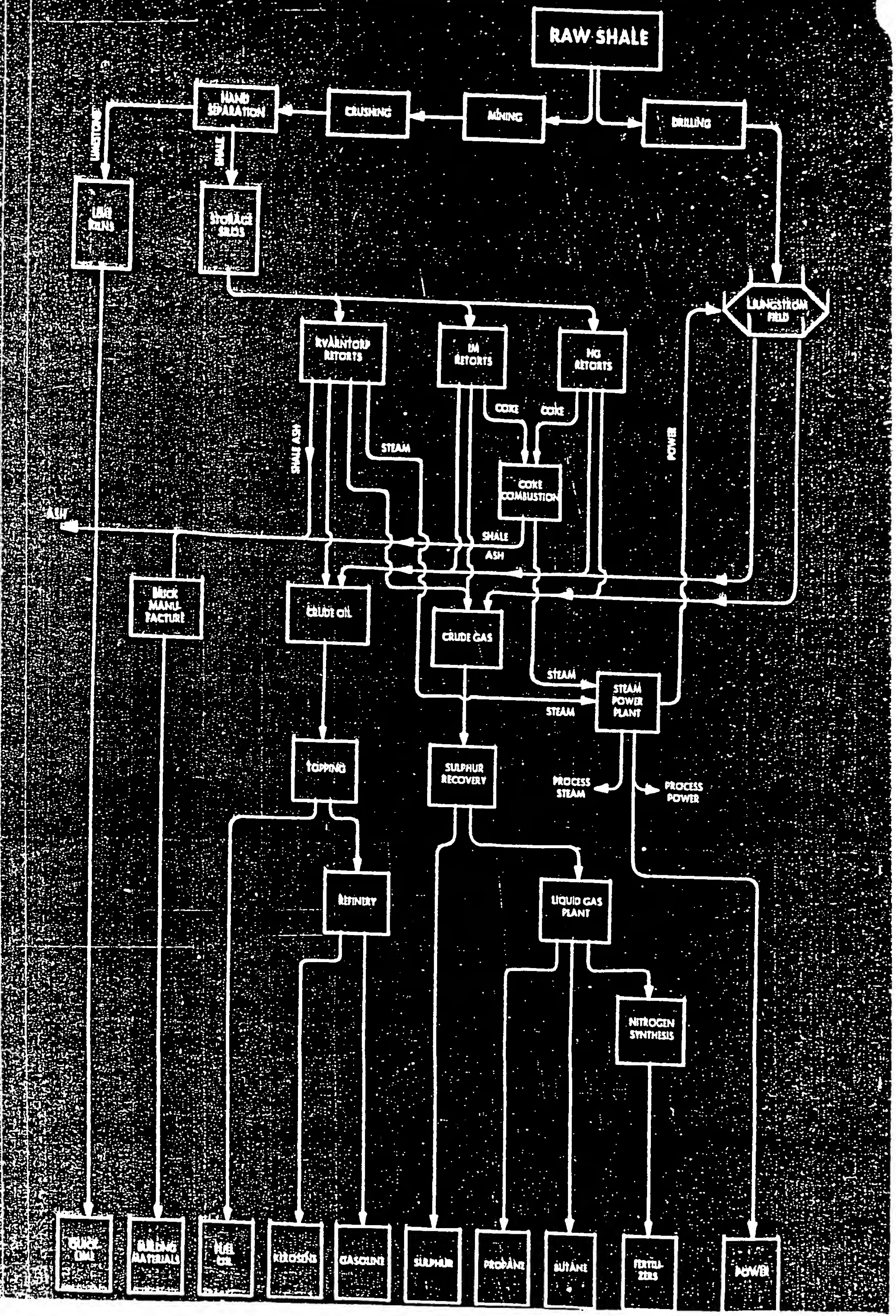
Fig. 32. Canteen.

Conclusion

The results achieved at Kvarntorp during the ten-year period 1941—51 prove that Swedish enterprise and techniques have succeeded in solving the problem of bringing down the cost of producing oil from shale to levels permitting shale oil to compete in price with petroleum. This has been accomplished by combining several processes that are specially suited to Swedish conditions, through technical improvements and research which have led to the development of two important recovery methods, viz. the Kvarntorp retort and Ljungström methods, and through the large-scale recovery of by-products.

The first steps have thus been taken toward a complete utilization of the reserves of bituminous shale. There is every reason to expect that in the years to come this branch of industrial enterprise will stride farther ahead and that realization of the immense potential possibilities of shale will give birth to a world-wide shale oil industry.




RAW SHALE
MINING
DRILLING
CRUSHING
HAND SEPARATION
LIMESTONE
SHALE
LIME KILNS
STORAGE SILOS
LJUNGSTROM FIELD
KVARNTORP RETORTS
IM RETORTS
HG RETORTS
COKE
COKE
COKE COMBUSTION
SHALE ASH
STEAM
POWER
ASH
SHALE
ASH
BRICK MANUFACTURE
CRUDE OIL
CRUDE GAS
STEAM
STEAM
STEAM POWER PLANT
TOPPING
SULPHUR RECOVERY
PROCESS STEAM
PROCESS POWER
REFINERY
LIQUID GAS PLANT
NITROGEN SYNTHESIS
QUICK-LIME
BUILDING MATERIALS
FUEL OIL
KEROSENE
GASOLINE
SULPHUR
PROPANE
BUTANE
FERTILIZERS
POWER